Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

CONTRIBUTIONS FROM THE JEFFERSON PHYSICAL LABORATORY,
HARVARD UNIVERSITY.

A SIMPLE METHOD OF MEASURING THE INTENSITY OF SOUND.

By George W. Pierce.

Presented January 8, 1908. Received January 4, 1908.

I. Introduction.

In the course of a series of experiments on Detectors for Electromagnetic waves the writer has found a number of solid substances which, when supplied with contact electrodes and put into electric circuits, serve as rectifiers for small electric oscillations. Some of these substances used in connection with a galvanometer prove to be extremely sensitive and constant in their action and permit the measurement of the currents generated by the vibration of the diaphragm of a magneto-telephone under the action of sound waves even when the telephone is at a considerable distance from the source of sound.

With the use of this device the relative intensity of sound at different positions in a room may be measured, and many interesting results as to the acoustic properties of an auditorium may be obtained.

The study of the rectifiers themselves is the subject of a series of papers by the writer, on "Crystal Rectifiers for Electric Currents and Electric Oscillations." Part I of this series of papers appeared in the Physical Review for July, 1907, Vol. XXV, pp. 31–60. The rectifier there investigated is Carborundum. Several other crystal bodies, some of which are in their action much more sensitive than carborundum, possess similar properties and are being experimentally studied in detail with reference to their electrical characteristics and with reference to their use in electric-wave telegraphy.

The results of this study will constitute the subject matter of succeeding parts of the Physical Review article.

II. Molybdenite as a Rectifier for Electric Oscillations.

One of the most sensitive of the rectifiers thus far investigated is Molybdenite. The present paper deals with the use of the molybdenite rectifier in the measurement of sound.

Molybdenite is also an extremely sensitive detector for electric waves in wireless telegraphy, and may also be employed in experiments on telephony and in many other experiments where it is required to measure small electric oscillations.

The manner of mounting and employing the substance is substantially the same in these several applications, and is capable of several variations, only one of which will be given here. Molybdenite, MoS_2, is a mineral occurring in nature in the form of hexagonal prisms with eminent cleavage parallel to the base, and may be scaled off in thin sheets, a few sq. cm. in area, resembling bits of tin-foil. In the present experiments a thin sheet so obtained was mounted in the manner shown in the sectional drawing of Figure 1.

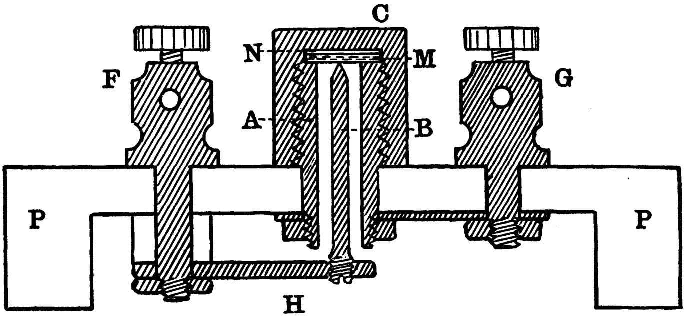

Figure 1. — Rectifier.

A thin, circular piece of molybdenite[1] (M, Figure 1), about 1 sq. cm. in area, is clamped tightly between a piece of mica N and the hollow brass post A, by means of a brass cap C screwed down on the post A. The molybdenite is thus held in electrical connection with the annular surface of the end of the hollow brass post A, which is in turn metallically connected with the binding post G. Separated from A by an air space, a small pointed brass rod B is screwed up through a metallic strip H attached to a second binding post F. The binding posts and the holder for the molybdenite are rigidly supported by a porcelain base PP. The seat of the action of the molybdenite as a rectifier is at the small region of contact between the molybdenite and the pointed rod. In the construction of the rectifier this contact is adjusted by screwing the rod up through H until a galvanometer in series with the device and a source of alternating voltage (of about .05 volt) gives a maximum deflection. The adjustment of the contact is made once for all, and subsequent accidental changes of the apparatus is prevented by filling the cavity about H with melted wax or plaster of Paris.

---

[1] Molybdenite free from iron should be used.

When made in this manner the rectifier will stand considerable abuse in the way of jar and overload. It is, however, subject to changes due to the expansion and contraction of the mounting, and due also possibly to a temperature coefficient of the molybdenite itself. Effort to get a mounting without such changes with temperature and a study of the temperature coefficient of the substance itself are now in progress. Up to the present it is found advisable to use the rectifier in a thermostat at constant temperature, when accurate quantitative agreement between observations extending over a considerable period of time is required.

Whether or not the direct current obtained from the molybdenite in contact with two unequal electrodes is a thermo-electric action due to the unequal heating of the electrodes by the oscillating current is at present not known. It will be seen that the conditions are favorable for such thermo-electric action. In order not to commit one's self to any particular theory as to the nature of the action, the device is here referred to as a "rectifier," in that the current in one direction due to an impressed voltage is very different from the current in the opposite direction under the same voltage.

III. Electric Circuits Employed with the Molybdenite Rectifier in Experiments on Sound.

In the measurement of sound, the rectifier was at first placed directly in series with a sensitive galvanometer and a Bell magneto-telephone receiver. With this arrangement, when sound was made in the neighborhood of the receiver, the vibration of the telephone diaphragm generated electric oscillations in the circuit. These oscillations passed through the rectifier more strongly in one direction than in the opposite direction, and caused a deflection of the galvanometer.

However, on account of the high resistance of the rectifier, and in order to take advantage of electrical resonance in the circuits, it was found better to employ an arrangement of circuits containing a step-up transformer, as is shown in Figure 2.

In Figure 2 PS is a transformer, the primary P of which is connected in series with the telephone T and an adjustable condenser C. The secondary S of the transformer is connected in series with the rectifier R, the galvanometer G, and a calibrating device at W. By adjusting the condenser C, the electric circuit TCP was brought to resonance with the alternating voltage impressed on the system by the periodic impact of the sound waves. This adjustment was easily made experimentally.

The proper choice of the transformer PS and the telephone T was a more difficult problem. A theoretical solution of this problem was not at hand, on account of lack of knowledge of the characteristics of the telephone when used as a generator of oscillatory currents and on account of the fact that the current through the crystal in the secondary is not a simple function of the voltage in this circuit (see Figure 6). Some aid in the choice was had in the following considerations, which served to point vaguely the direction in which experiment was to be made :

1. Since the primary circuit was to be brought to resonance with the oscillations, the inductance of the primary circuit is negligible, if we may neglect the reaction of the secondary circuit on the primary. With this approximation it follows from elementary considerations that the resistance of the primary coil should be equal to the resistance of the telephone. Experiment soon showed that the reaction of the secondary circuit was not negligible, and since the effect of the reaction of the secondary is to increase the apparent resistance of the primary, it follows that the resistance of the primary coil should be somewhat less than that of the telephone.

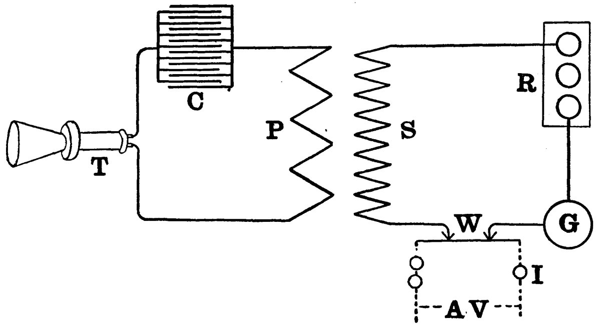

FIGURE 2. — Electric circuit.

2. The iron core of the transformer should be such as to be properly magnetizable by the current generated by the telephone, which in frequency and intensity approaches to the current used in telephony. Whence it seemed probable that the small terminal transformers used in telephony would have about the proper amount of iron for use in the present experiments.

3. The resistance of the secondary of the transformer and that of the galvanometer should be high because the resistance of the crystal for a small current is several thousand ohms.

Guided by these considerations, and by the results of preliminary experiments with several small induction coils, two transformers were wound, of which the one that proved the more satisfactory had the following dimensions :

Length of iron core, 9.5 cm.
Diameter of iron core, 1 cm.
Depth of channel, 1.5 cm.

In this channel were three coils of which either pair could be used as primary and secondary. These three coils had respectively 16, 280, and 720 ohms resistance.

With this transformer experiments were made with three different telephones, of which a Siemens and Halske "Lautsprecher," rewound to 466 ohms, and provided with a small conical sound collector 10 cm. in diameter, proved the most sensitive. This telephone was ordinarily used with the 280 ohm primary and the 720 ohm secondary. The other two telephones used had resistances of 53.8 and 99.8 ohms respectively, and were used with the 16 ohm primary and the 720 ohm secondary.

Experiment I. Adjustment of the Receiving Telephone Circuit to Resonance with the Sound. — After having made a preliminary selection of the pitch to be employed in a particular experiment, it becomes important to adjust the electrical circuit to resonance with this pitch. The following data is given to show the manner in which this adjustment is made, and to show the effect of such a resonant adjustment in increasing the sensitiveness of the apparatus.

An organ-pipe $F\sharp_4$ giving 705 complete vibrations per second, supplied by air from bellows operated by an electric blower and set up in the Constant Temperature Room [2] of the Jefferson Physical Laboratory, served as source of the sound.

The telephone receiver, having a resistance of 53.8 ohms, and provided with a conical sound-collector 29 cm. in diameter, was placed at a distance of about 1.5 meters from the organ-pipe. The 16 ohm primary and the 720 ohm secondary of the transformer, Figure 2, were employed. The galvanometer G was a d'Arsonval type and had a resistance of 538 ohms, and gave a throw of one scale division ($\frac{1}{10}$ inch) for a current of 1.53×10^{-8} amperes.

---

[2] This room is described in Professor Sabine's paper on "Architectural Acoustics, Part I, Reverberation," published in the American Architect, Vol. XLVIII, April–June, 1900, and in Contributions from the Jefferson Physical Laboratory, Vol. IV, 1906. This room was used in some of the present experiments because the apparatus for producing the sound happened to be in place there. The apparatus was in use by Professor Sabine, and together with other parts of the apparatus, including two of the receiving telephones, was kindly placed by him at my disposal.

The condenser C, Figure 2, having a total capacity of 1 microfarad, and adjustable by steps of .05 microfarads, was given various values, and the corresponding throws of the galvanometer when the pipe was sounded were taken. In taking these readings the pipe was left sounding until the coil of the galvanometer had completed its swing.

The results are recorded in Table I.

TABLE I.

Adjustment of Electric Circuit to Resonance with Sound Frequency.

Capacity of C in Microfarads.	Current through Galvanometer in Microamperes.
.00	.000
.20	.064
.30	.308
.45	.477
.50	.470
.60	.320
.80	.206
1.00	.157
C short-circuited	.061

The curve of Figure 3 is plotted from the data of Table I. The horizontal dotted line through the figure is the current with the condenser short-circuited. This curve gives an idea of the advantage obtained by the use of the proper capacity in the primary circuit of Figure 2. The maximum of the curve shows a value of the current that is nearly eight times the current obtained when the condenser was short-circuited.

IV. STATIONARY SOUND WAVES. DISTRIBUTION OF INTENSITY.

In taking the data of Experiment I, the position of the telephone receiver and that of the organ-pipe were left constant. When the telephone was removed to different parts of the room, very striking evidence of a stationary-wave system was obtained. This stationary system was, however, extremely complicated. In some positions, for example, a very slight change of the inclination of the sound-collecting cone, without any motion of the receiver as a whole toward or away from the source of sound, would cause several hundred per cent change of the reading of the galvanometer. Professor Sabine has already called attention to the existence in this room of a striking interference system. The following paragraph descriptive of the phenomenon is quoted from his writings on the subject :

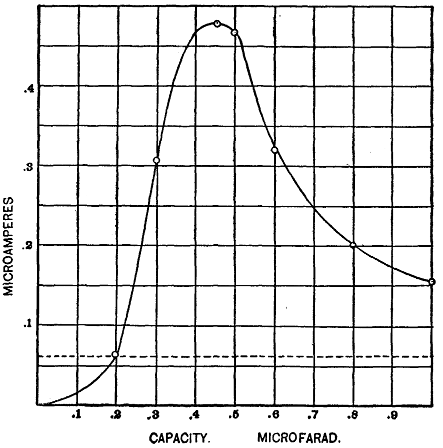

FIGURE 3. — Resonance curve.

"This room is here described at length because it will be frequently referred to, particularly in this matter of interference of sound. While working in this room with a treble *c* gemshorn organ-pipe blown by a steady wind pressure, it was observed that the pitch of the pipe apparently changed an octave when the observer straightened up in his chair from a position in which he was leaning forward. The explanation is this : The organ-pipe did not give a single pure note, but gave a fundamental treble *c* accompanied by several overtones, of which the strongest was in this case the octave above. Each note in the whole complex sound had its own interference system, which, as long as the sound remained constant, remained fixed in position. It so happened that at these two points the region of silence for one note coincided with the region of reinforcement for the other, and *vice versa*. Thus the observer in one position heard the fundamental note, and in the other, the first overtone. The change was exceedingly striking, and as the note remained constant, the experiment could be tried again and again. With a little search it was possible to find other points in the room at which the same phenomenon appeared, but generally in less perfection."[3]

Before undertaking the study of the complicated distribution of sound intensity in a room with highly reflective walls, it was decided to become better acquainted with the present experimental method by an examination of a much simpler interference system; namely, that produced as nearly as may be by a single reflecting surface. This is done in Experiment II following. Afterward, in Experiment III, it is shown to be practicable to extend the investigation to a quantitative determination of the distribution in a large auditorium.

Experiment II. Stationary Wave Produced by a Single Reflecting Surface. — The arrangement of apparatus is shown in Figure 4. In order to reduce the effects of reflection from the walls of the room, they were curtained off with felt, F, 1.1 cm. thick, hung at a distance of about 50 cm. from the walls. Felt of the same thickness was also placed overhead, separated from the ceiling by about 50 cm.

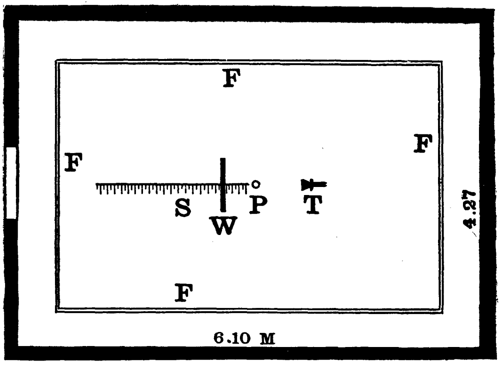

FIGURE 4. — Position of apparatus in constant temperature room.

The organ-pipe, F♯$_4$, 705, serving as a source of sound, was placed at P, near the center of the room. The telephone receiver, used in Experiment I, was placed at T, about 70 cm. from the pipe. Leads ran from the telephone to the condenser and transformer, which together with the observer and galvanometer were in a distant room.

A reflecting surface of wood, 73 cm. wide by 122 cm. high, was placed vertically at W, and was mounted on a track so as to be capable of displacement along the scale S. The open end of the pipe was placed at a height of 61 cm., and was therefore on a level with the middle of the reflector.

---

[3] Sabine, loc. cit. p. 8.

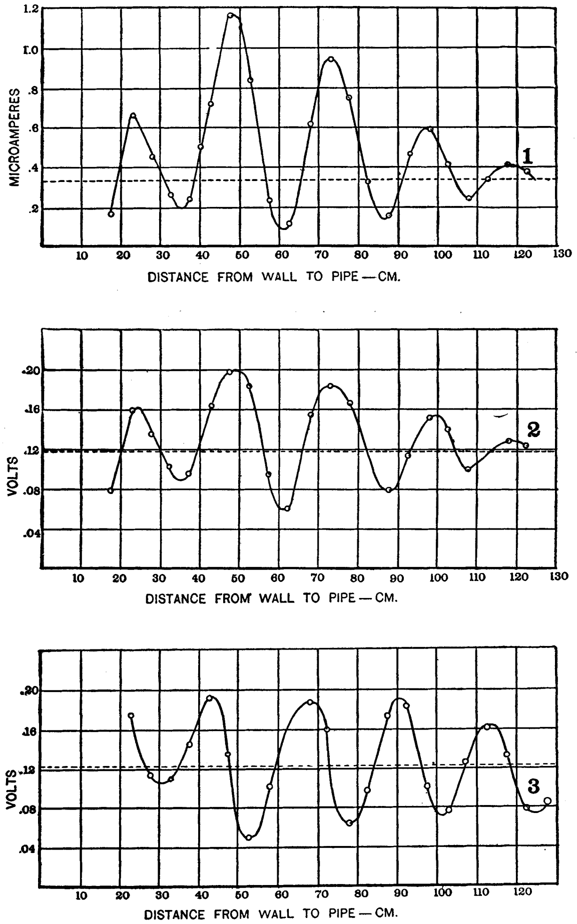

FIGURE 5. — Curve 1, stationary wave in terms of current in secondary. Curves 2 and 3, stationary waves in terms of voltage in secondary.

The distance from the reflector W to the pipe P could be varied and was read off on the scale S. Readings of the galvanometer were taken with the reflector at various stages, 5 cm. apart, along the scale. The values of the current in the galvanometer circuit are plotted against the distance of the reflector from the pipe, in Curve 1 of Figure 5. This curve shows the stationary wave system set up by the interference of the direct and the reflected waves. The distances between alternate nodes and alternate loops of the curve give the following values of the wave-length :

49.7, 49., 45.8, 51, 46.5 ; Average, 48.4.

The velocity of sound at the temperature of the room, 18°, was 34200 cm. per second, whence the period

$$n = \frac{34200}{48.4} = 706,$$

while the actual value of the pitch of the pipe $F\sharp_4$ is 705 vibrations per second. This agreement is evidently better than is to be expected from the method, on account of the uncertainty of locating the nodes and loops of the curve.

It is seen, however, that the points of the stationary wave lie well on the curve. A repetition of the observation on a succeeding day gave substantial agreement with Curve 1. It is to be observed that the first maximum, with the reflector in the neighborhood of 23.5 cm. from the pipe, is weaker than the second and third maxima. This is probably caused by the fact that the wind-chest on which the pipe was mounted intercepted the reflected wave more strongly when the reflector was close up than when it was more distant from the pipe.

The horizontal dotted line through the curve at 3.30 gives the magnitude of the current when the reflector was removed. It is seen that the peaks of the curve above the line of no reflector are much greater than the neighboring depressions of the curve below the line. This distortion was found to be chiefly due to the current-voltage characteristic of the rectifier, and is eliminated by the calibration of the rectifier with an alternating voltage, and by plotting the stationary wave in terms of alternating voltage instead of galvanometer current.

In making the substitution of voltage for current it would be instructive to impress the known alternating voltage on the primary of Figure 2, and take the corresponding throws of the galvanometer in the secondary. We should then be able to know the voltage generated by the telephone when we know the galvanometer current. However, on account of the influence of the transformer, this could be properly done only with an alternating voltage of the same frequency as the sound, in this case 705 cycles. A generator for this frequency was not at the writer's disposal, so it was decided to calibrate the secondary circuit instead of the primary. For this, a 60 cycle alternating voltage could be employed without much error; for a preliminary experiment had shown that the impedance of the secondary of the transformer was practically negligible in comparison with the resistance of the rectifier, and that the current-voltage characteristic of the rectifier, as far as tests could be made with means at hand, was independent of the frequency.

The calibration of the secondary circuit was made as follows: The slide wire of a potentiometer was inserted at W in Figure 2, and a source of alternating voltage was applied at AV. The drop of potential in W was known from the resistance of W and the readings of an alternating current ammeter at I. The alternating voltage in W was varied by varying the resistance of W, and the corresponding direct current in the galvanometer was read. These values are plotted in Figure 6.

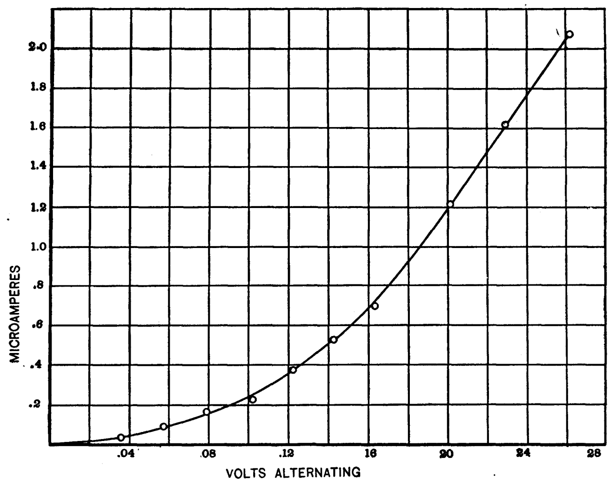

Figure 6. — Current-voltage characteristic of rectifier.

If now we replace the current values in Figure 5 by the corresponding voltage values in the secondary of the transformer we obtain Curve 2 of Figure 5. This curve is independent of the rectifier, and shows the number of alternating volts at the terminals of the secondary of the transformer of Figure 2 for various positions of the reflecting wall in Figure 4. Except for distortion of the wave when the reflector was too close to the pipe this curve is nearly symmetrical about the line of no reflector.

Curve 3 of Figure 5 is another curve obtained in the same way with a slate reflector at W and a pipe of slightly higher pitch, and with the Siemens and Halske telephone, which had a much smaller sound collecting cone, 10 cm. in diameter. This curve is somewhat more nearly symmetrical in character.

It should be noted in respect to these curves that there was still considerable reflection from the room, in spite of the felt curtains, and that these reflected waves act in a manner to distort the stationary system.

The curves of Figure 5, although taken under somewhat artificial conditions are in themselves instructive, in showing the marked effect of a reflecting wall on the loudness and quality of sounds. When a speaker or an orchestra is at any given distance in front of a reflecting wall certain tones will be greatly reduced in intensity while tones of a different pitch will be greatly intensified, thus it may be changing completely the emphasis and quality of the composition. When there is only a single strongly reflecting wall (the other walls being strongly absorbtive) this distortion occurs over practically the whole room, although, of course, at different points in the room different notes will be suppressed or emphasized depending on the phase difference between the direct and reflected waves to the auditor.

Experiment III. Interference of Sound Waves in a Large Lecture Room. — In order to extend the investigation to the study of the distribution of sound intensity in a room of considerable proportions, an organ-pipe and the telephone receiver were set up in the large lecture room of the Jefferson Physical Laboratory. This room, of which a diagram is shown in Figure 7, is 18.6 meters long, 12.7 meters wide, and 7.7 meters high at one end. It contains seats for about 300 students. These seats are progressively raised toward the back of the room so that the height of the ceiling above the seats in the rear is about 4 meters. The walls of the room are of brick.

The organ-pipe used as a source of sound, G_4, 768, was placed at the position P in the diagram, and was supplied with wind at a constant pressure from a reservoir, from which the air supply to the pipe was turned on and off by an electro-pneumatic valve operated by a battery and clock work.

The Siemens and Halske telephone receiver, 466 ohms, with the sound-collecting cone 10 cm. in diameter, was used as a receiver for the sound and was provided with a long double lead so that it could be placed anywhere in the room.

The first position chosen for the receiver was at the extreme rear of the room (1, Figure 7), where a small track 10 cm. wide and 2 meters long was run out perpendicularly from the wall. The telephone was placed on this track with the opening of the sound collector toward the wall, and readings of the galvanometer were taken with the telephone at various distances from the wall. The results obtained are plotted in Curve 4 of Figure 8. The abscissae of this curve are the distances in centimeters from the wall measured to the opening of the sound collector; the ordinates are the corresponding values of the current obtained in the galvanometer when the organ-pipe was sounded. The first reading, .73 $\times$ 10^{-7} amperes, was obtained with the opening of the sound collector of the telephone jammed tight against the brick wall. On withdrawing the receiver from the wall by stages of 5 cm., while keeping the opening of the sound collector always toward the wall, the succeeding values of the curve were obtained, showing the occurrence in this part of the room of very decided maxima and minima of

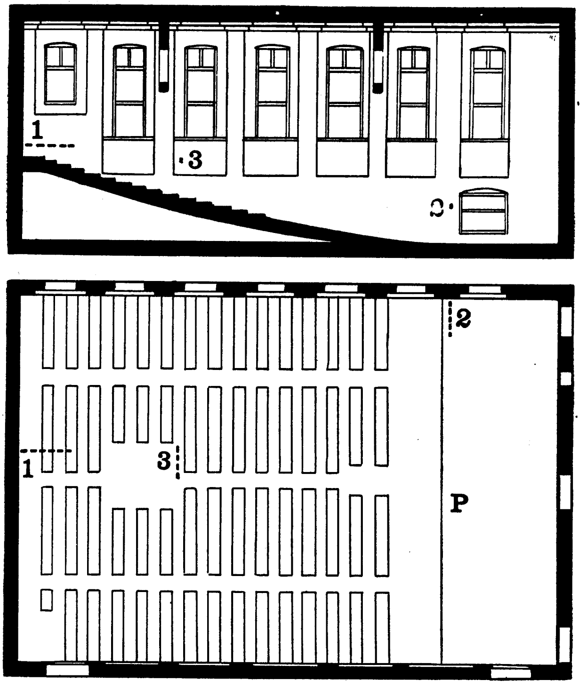

FIGURE 7. — Diagram of large lecture room. P is the position of the source of sound; 1, 2, and 3, positions of the receiver.

sound intensity. The irregularities of the curve were actually existent in the interference system and were verified by a repetition of the experiment.

In the above curve the current obtained at the best of the maxima was 3.30×10^{-7} ampere. When it is noted that this was at a distance of 15 meters from the source of sound, it will be seen that the receiving apparatus possesses quite remarkable sensitiveness. Of course, too much importance must not be given to the distance from the source as a determining factor of the intensity, for, as will soon appear, this particular position, accidentally chosen, in the rear of the room was a position in which the sound was more intense than at many places much nearer to the source. However, even with a galvanometer of only moderate sensitiveness it was possible to extend the investigation satisfactorily to any part of the room. Curves of results at two other positions in the room are discussed below.

The question arises, how may we determine the exact region of space to which the indications belong? In Curve 1 of Figure 8 a maximum was found when the opening of the receiver was 5 cm. from the wall. Is the maximum of sound vibration at the opening of the cone, and, therefore, 5 cm. from the wall or is it inside the cone or outside the cone? Can we locate its exact position? In attempting to answer these questions it was decided to try the effect of reversing the telephone so that the opening pointed away from the wall. With the telephone thus reversed Curve 5 of Figure 8 was obtained. Unfortunately, on account of the size of the telephone and cone, it was not possible to extend the observations to points nearer the wall than 40 cm. The distance measurements for this curve were also made from the wall to the opening of the cone. By a comparison of this curve with Curve 4 we may get some evidence of the location in space of the sound vibration.

The two maxima of Curve 5 probably correspond respectively to the two right hand maxima of Curve 4, as is evidenced by their distance apart, and their relative amplitudes, and by the distance apart of the minima of Curve 5 as compared with the minima at 75 and 108 of Curve 4. Now it is seen by inspection that these two curves would be brought into coincidence as to location of maxima and minima, if, instead of having measured from the wall to the opening of the cone of the telephone, we had measured to a point 5.7 cm. outside of the cone; that is to say, the indications of the galvanometer are indications as to *the relative amplitude of the sound vibration at a point* 5.7 *cm. outside of the opening of the sound-collecting cone.*

While this reasoning is not entirely conclusive without further evidence, because of the possible actual disturbance of the stationary system by the reversal of the telephone, yet the result seems highly probable on account of its agreement with the familiar fact that the maximum of motion of the air column of a tubular resonator is outside the end of the resonator. The sound-collecting cone of the present apparatus is a resonator for the pitch employed — in fact, the particular pitch was selected by a preliminary experiment which showed that the air column of this cone was in resonance with the pitch — and this resonant air column, according to deductions from the above experiment, is thrown into most active vibration when a region just outside (5.7 cm.) the opening of the cone is coincident with a region of large displacement.

This result enables us to locate the actual position of the nodes and loops of Curve 4, Figure 8. Each point of the curve belongs to a region of space 5.7 cm. nearer to the wall than the corresponding abscissa; therefore, the first maximum of motion, which was obtained with the opening of the cone 5 cm. from the wall, is really .7 cm. behind the wall, — that is to say, practically *coincident with the wall.*

In order to examine the distribution of sound intensity in the neighborhood of another portion of the wall of the room, the telephone receiver and its track were placed at 2 in Figure 7, and the galvanometer readings were taken with the opening of the cone turned toward the wall and placed at various distances from the wall. Curve 6 of Figure 8 was obtained as representative of the distribution at this position. Here again the corrected position of the first maximum is practically coincident with the wall. The interference system in this locality is much more irregular than in position 1, and the maxima with the exception of the maximum at 90 cm. are less intense than those at position 1. This is interesting when we note the fact that the distance of the position 2 from the source of sound is only one half as great as the distance of position 1. For hearing this particular note the position at the back of the room is more favorable than the much nearer position at the side of the room, notwithstanding the fact that the side position was directly in front of the lip of the pipe and was unobscured by intervening objects, while a line running from the source of sound to the position in the rear of the room passed immediately over the backs of numerous benches with which the room was furnished.

At a third position in the room, position 3, Figure 7, an interval of 100 cm. was investigated. The results obtained are shown in Curve 7, Figure 8. These distances (abscissae) are measured from an arbitrary origin. The opening of the cone of the telephone was turned toward the spot marked "3" in the elevation drawing of Figure 7. Here again a fairly definite stationary system was found. This position is also less favorable for hearing this particular tone than the position 1 in the rear of the room.

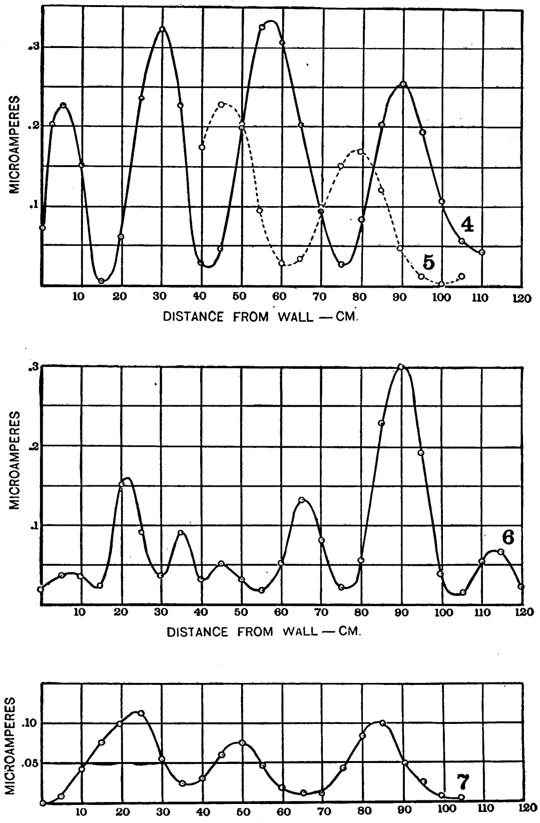

FIGURE 8. — Stationary waves in large lecture room.

These experiments were made in the large lecture room which is immediately over the machine shop of the laboratory, and were apparently not in any way affected by the very considerable vibration and noise of several motors and lathes in almost continual operation. The rectifier is, however, extremely sensitive to electric waves; and electric disturbances, when they happen to be in syntony with the rectifier circuit may prove troublesome. In the course of the present experiments the breaking of a chronograph circuit by an electric clock in a distant room gave noticeable deflections. Most of these electric disturbances may be easily tuned out by a change of the inductance or capacity either in the disturbing circuit or in the rectifier circuit. By wearing a head telephone connected in series with the galvanometer during the observations, the observer may easily recognize any foreign disturbances by their characteristic tones in the telephone.

It was not the purpose of the present note to multiply observations on the acoustic properties of a particular room. However, apart from the interest attaching to the method of the experiment, the result that for a sustained tone, even in a large room, there are practically all over the room definite positions of sharp maxima and minima of intensity is rather a striking fact when brought out objectively. The results show that an auditor may sometimes greatly improve his hearing of a discourse or a musical rendition by a slight motion of his head so as to bring his ear into a position of maximum intensity. Perhaps he already unconsciously does this, which may account for the fixed attitude of an audience in close attention.

The occurrence of these definite maxima and minima of intensity of sound, due to reflection from the walls, should be borne in mind when one attempts to interpret any experiment on sound performed in a closed room. As Professor Sabine has repeatedly emphasized, the mere fact that the walls are distant from the source of sound, while the observer, or sound-receiving apparatus, is near to the source, is not sufficient precaution against the influence of reflection, because the reflecting surfaces are on all sides and act many times, and may combine in their action in such a manner as to be a very considerable factor in the resulting intensity.

The curves of Figure 8 are plotted in terms of current in the galvanometer. It was shown above, in Experiment II, how the indications of the galvanometer may be made independent of the rectifier by substituting voltage from the curve of Figure 6 for the corresponding current values. When this substitution is made, the proportional differences between the maxima and minima, expressed in voltage values, become somewhat smaller than these differences expressed in current values. However, on account of the intermediation of the telephone receiver between the sound vibrations and the electrical indications, it is still not possible, without further calibration of the apparatus, to obtain absolute or even relative values of the sound intensity. Several methods of obtaining this calibration in terms of sound intensity suggest themselves. One method is to employ the distance law in connection with experiments performed in the open. Another method, which is perhaps more interesting, would be to study directly the characteristics of the magneto-telephone when used as a generator, by measuring directly the amplitude of vibration of the telephone diaphragm and then measure with the rectifier the resulting alternating voltage.

V. Sensitiveness of the Method.

The galvanometer employed in the above experiments was not particularly sensitive. Its resistance was decidedly too low and entirely inappreciable in comparison with the resistance of the rectifier. A galvanometer of the highest attainable resistance would hardly be appreciable in resistance in comparison with the resistance of the rectifier. Also the transformer employed between the telephone circuit and the rectifier circuit did not have high enough resistance in its secondary. With evident improvements in these respects the sensitiveness of the apparatus could be greatly increased, in case one should desire to measure extremely feeble sounds. However, without such improvements the sensitiveness of the apparatus seems to greatly exceed that of any of the physical methods heretofore employed for the measurement of sound.

For a deflection of .2 millimeters on the galvanometer scale, the power in the galvanometer circuit, calculated from the current-voltage curve of Figure 6, amounted to 1.53×10^{-5} ergs per second, while Lord Rayleigh[4] finds the minimum energy that will affect the human ear to be 1.11×10^{-5} ergs per second, for a pitch of 2730 vibrations per second. That is to say, with the apparatus of the present experiments, in order to get .2 mm. deflection it is necessary to develop energy in the galvanometer circuit at about the rate at which energy is received by the human ear at minimum audible intensity. On account of the inefficiency of the magneto-telephone receiver when used as a phono-electric generator, energy at a rate much greater than this is required by the magneto-telephone receiver in order that this amount of power may get into the electric circuits.

The use of a carbon transmitter in place of the magneto-telephone receiver for the sound receptor, while not so constant as the magneto-telephone, is of course enormously more sensitive. With this arrangement the condenser C of Figure 2 was replaced by a battery of four storage cells, and a transformer of lower resistance primary was employed. Preliminary tests showed that the galvanometer would then be thrown off the scale when a small organ-pipe was sounded almost anywhere on the same floor of the building, even when the passage of the sound from the pipe to the transmitter was through long corridors and several partly closed doors. With the pipe at P and the transmitter, without sound-collector, placed at 3 in the room shown in Figure 7, a delicate Weston ammeter gave a whole scale deflection, which corresponded to a current of 392 microamperes. With the use of this ammeter instead of the galvanometer readings could be taken with great rapidity and may be easily made self-recording.

---

[4] Lord Rayleigh, Proceedings of the Royal Society, 1877, Vol. 26, p. 248.

To test further the sensitiveness of the apparatus with the carbon transmitter substituted for the magneto-telephone receiver, this transmitter was supplied with long leads and placed outside the building. An assistant was sent off across an open field. When the assistant blew a small organ-pipe, C_5, 1024, at a distance of 100 meters away, a deflection of 5 mm. corresponding to a current of 3.06×10^{-8} amperes was obtained. A locomotive whistle at a distance of perhaps a mile gave 75 millimeters deflection.

Jefferson Physical Laboratory,
Harvard University, Cambridge, Mass.
December 27, 1907.